Probing the Impact of Stellar Duplicity on Planet Occurrence with Spectroscopic and Imaging Observations

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1 Introduction

Over the last eleven years, Doppler spectroscopy has been very successful at detecting and characterizing extrasolar planets, providing us with a wealth of information on these distant worlds (e.g. [59]). One important and considerably unexpected fact these new data have taught us is that diversity is the rule in the planetary world. Diversity is found not only in the characteristics and orbital properties of the ∼210 planets detected thus far[3], but also in the type of environment in which they reside and hence in which they are able to form. This observation has prompted a serious revision of the theories of planet formation (e.g. [12, 33, 40]), leading to the idea that planet formation may be a richer and more robust process than originally thought.

It is well known that nearby G, K, and M dwarfs are more likely found in pairs or in multiple systems than in isolation. Specifically, 57% of the G-dwarf primaries within 22 pc of the Sun have at least one stellar companion [10]. The multiplicity among K dwarfs is very similar [13, 24], while the multiplicity among nearby M dwarfs is close to 30% [8, 21]. Altogether, these figures imply that more than half of the nearby F7–M4 dwarfs are in binaries or in higher order systems. Since these stars constitute the bulk of targets searched for extrasolar planets via Doppler spectroscopy, the question of the existence of planets in binaries and multiple stars is fundamental and cannot be avoided when one tries to assess the overall frequency of planets.

From the theoretical perspective, the existence of planets in binaries and multiple stars is not guaranteed a priori, as the presence of a stellar companion may disrupt both planet formation and long-term stability. On the other

[3] See the Extrasolar Planet Encyclopedia, http://exoplanet.eu/, for an up-to-date list.

hand, young binary systems usually possess more than one protoplanetary disk, meaning that planets may form around any of the two stellar components (circumstellar planets) and/or around the pair as a whole (circumbinary planets). Although theoretically both circumstellar and circumbinary planets should exist, our present observing programs are aimed at detecting circumstellar planets and only these latter will be considered in this chapter. Our discussion will furthermore be focused on giant planets, which are less challenging to detect by means of the Doppler spectroscopy technique than lower mass planets.

Two different scenarios have been proposed to explain the formation of gaseous giant planets. According to the core accretion model, giant planets form in a protoplanetary disk through the accretion of solid planetesimals followed by gas capture (see e.g. [33] for a review and references). Despite some remaining uncertainties, this model has the advantage of doing a fairly good job in explaining the existence of both the terrestrial and the giant planets in the Solar System, and so is considered as the favored formation mechanism for planets. With regard to planet formation in binaries, an important point in this model is that the protoplanetary cores that give rise to the giant planets have to form beyond the snow line (i.e. beyond 1–4 AU for solar-type stars) to benefit from the presence of ices as catalysts.

An alternative way to view giant planet formation is to consider that gaseous giant planets form by direct fragmentation of the protoplanetary disk. This is the so-called disk instability model (see e.g. [12] for a review and references). This scenario is still somewhat speculative in that it is not clear yet whether real protoplanetary disks actually meet the requirements to fragment. Furthermore, even if they do, it is far from certain that the fragments will be long-lived and contract into permanent planets. Given the many uncertainties and difficulties related to theoretical work on planet formation via disk instability, observational tests that would help characterizing and quantifying the likelihood of forming giant planets by this channel are highly desirable.

Regardless of the exact formation process, tidal perturbations from a close stellar companion may affect planet formation by truncating, stirring, and heating a potential circumstellar protoplanetary disk (e.g. [1, 4, 36, 41, 48]). Disk truncation is a serious concern as it reduces the amount of material available for planet formation and as it may cut the disk inside the snow line. This is a direct threat to planet formation and it explains why the naive outlook for planet formation in close binaries is pessimistic. The impact of disk stirring and heating on planet formation is not so easily understood and requires dedicated simulations. Three main studies have been done so far, reaching somewhat different conclusions as to the likelihood of forming giant planets in binaries closer than 50–60 AU. According to [41], giant planet formation is inhibited in equal-mass binaries with a separation of 50 AU whatever the formation mechanism, whereas [4] claims that giant planets are able to form in binaries with periastrons as small as 25 AU. On the other hand, [36] showed that the protoplanetary disk mass has a strong impact on the final results and

that the two possible formation mechanisms yield different predictions as to the occurrence of giant planets formed in light disks. This has a very interesting consequence, namely that planets in binaries might provide a unique data set to test theoretical predictions and to possibly identify the main formation mechanism for giant planets.

Assuming that planets can indeed form in various types of binary systems, another question is that of their survival. The extensive body of literature on this subject can be summarized as follows. For low-inclination planetary orbits ($i \lesssim 39°$), the survival time is primarily determined by the binary periastron value and a stellar companion with a periastron wider than about 5–7 times the planetary semimajor axis does not constitute a serious threat to the long-term (∼5 Gyr) stability of Jovian-mass planets (e.g. [20, 26]). The survival time of planets on higher inclination orbits depends not only on the periastron value but also on the inclination angle, meaning that planetary orbits become more easily unstable, and this even if the periastron value is quite large (up to a few thousands of AU). This additional type of instability is due to the so-called Kozai mechanism, which causes synchronous oscillations of the planet eccentricity and inclination (e.g. [27, 56]).

To sum up, according to the present theoretical work if giant planets are to form in binaries with a separation below ∼100 AU, then the most sensitive (but also less understood) issue regarding their occurrence in these systems is whether or not the planets can form in the first place. This conclusion is very appealing, as it implies that quantifying the occurrence of planets in close binaries may be a means of obtaining some observational constraints on the process(es) underlying planet formation. However, a word of caution is needed here. Recent work made to explain the existence of a close-in Jovian planet around HD 188753 A has emphasized the alternative possibility that close double and multiple star systems originally void of giant planets may acquire one via dynamical interactions (stellar encounters or exchanges), in which case the present orbital configuration of the system would not be indicative of the planetary formation process [46, 49]. Pfahl & Muterspaugh [47] have tried to quantify the likelihood that a binary system could acquire a giant planet in this way and concluded that dynamical processes could deposit Jovian planets in ∼0.1% of the binaries closer than 50 AU. Therefore, to test the possibility of forming giant planets in binaries closer than ∼50 AU one needs not only to detect giant planets in these systems, but above all to quantify their occurrence.

From the observational perspective, the existence of planets in wide binaries and multiple stars has been supported by observations almost since the first discoveries. Indeed, in 1997 three planets were found to orbit the primary components of wide binaries [5], while another one was detected around 16 Cyg b, the secondary component of a triple star system [7]. The discovery of Gl 86 b a few years later [50] was another milestone, as it showed that Jovian planets can also form and survive in the much closer spectroscopic binaries. This discovery prompted a new interest in the study of planets in binaries,

raising the possibility that planets might be common in double and multiple star systems.

An important point to notice regarding the observation of planets in binaries is that radial-velocity planet searches used to be, and still are, strongly biased against the closest binaries. Double stars with an angular separation smaller than a few times the size (projected onto the sky) of the spectrograph fiber or slit are indeed difficult targets for radial-velocity measurements, as the two components simultaneously contribute to the recorded flux. This not only introduces additional possibilities for spurious velocity variations, but it also makes it much more difficult to precisely extract the radial velocity of one component. Using standard cross-correlation techniques, and even if only the radial velocity of the primary star is of interest, Doppler searches for planets in binaries closer than $\sim$2–6$''$ become severely hampered, if not definitely ruled out. As a consequence, current data only provide sparse information on the account of the closest binaries as possible abodes for planets, and quantifying the frequency of planets in these systems remains impracticable.

Recognizing early the importance and the interest of including binary stars in extrasolar planet studies, we have been investigating the impact of stellar duplicity on planet occurrence for a few years. In this chapter, we present some preliminary results from this dedicated investigation which has two main facets. One of our goals is to directly quantify the occurrence of giant planets in binaries with very different separations, from wide common proper motion pairs down to spectroscopic systems. Although close binaries are not well-suited targets for radial-velocity planet searches, dedicated reduction techniques based on two-dimensional correlation have recently been developed to simultaneously extract the radial velocity of each component [32, 67]. In many instances, the precision achieved by these techniques is at least good enough to search for Jovian planets around the primary star, meaning that Doppler surveys for circumprimary giant planets in close binaries are feasible. By combining the results from our "classical" radial-velocity planet searches conducted with ELODIE [45], CORALIE [50, 61] and HARPS [44] with those from our dedicated survey for giant planets in single-lined spectroscopic binaries [15, 18] we should therefore be able to quantify the occurrence of giant planets in binaries as a function of the binary separation and to test some of the theoretical predictions mentioned previously.

Another approach to the study of planets in binaries is to use direct imaging to trace out how stellar duplicity impacts on planet occurrence [14,17,18,58]. For instance, if the presence of a close stellar companion hinders planet formation or drastically reduces the potential stability zones, then the frequency of planets in close binaries should be lower than the nominal frequency of planets orbiting single stars. Alternatively, if the presence of a close stellar companion stimulates planet formation one way or another, planets should be more common in close binaries than around single stars. Reversing these statements, studying the multiplicity of planet-host stars relative to that of similar stars but without planetary companions may be a means of

quantifying whether or not stellar duplicity has a negative impact on planet formation or evolution.

This chapter is organized as follows. In Sect. 2 we present the results from classical radial-velocity planet searches, whose outcomes constitute the general framework within which lie more specific studies. In Sect. 3 we describe how direct imaging can be used to probe the global impact of stellar duplicity on planet occurrence and to test whether or not the frequency of planets is reduced in binaries closer than $\sim$120 AU. Finally, in Sect. 4 we discuss some preliminary results from our radial-velocity surveys dedicated to the search for circumstellar planets in spectroscopic binaries.

2 Results from Classical Radial-Velocity Planet Searches

Since 1995, radial-velocity planet search programs have yielded a wealth of information about the properties of extrasolar planets, unveiling an outstanding variety of orbital parameters and characteristics that still challenges our views of planet formation (e.g. [34, 59, 63]). This observational material, in turn, has been used quite extensively to get some insight into the formation and evolution processes at work in planetary systems (e.g. [16, 23, 52, 62]). Planets residing in double and multiple star systems are particularly interesting targets in this respect. Indeed, if the presence of a close stellar companion affects planet formation or evolution as suggested by several theoretical studies, some imprints of these effects may be recorded in the properties and characteristics of the planets found in binaries and multiple stars. We show here that in spite of their discrimination against the closest binaries, classical radial-velocity planet searches have already provided us with important observational constraints concerning the existence of planets in binaries.

2.1 Selection Effects Against Close Binaries in Classical Doppler Surveys

Doppler searches for planets around solar-type stars have always avoided close binaries, though the meaning of the term "close" differs from one program to another [29, 35, 45, 61]. As for our ELODIE and CORALIE surveys, G and K dwarfs belonging either to "short-period" single-lined spectroscopic binaries ($\lesssim$10 years) or to double-lined spectroscopic binaries were systematically rejected from the main samples [45, 61]. This discrimination was performed in the first place on the basis of former radial-velocity measurements gathered with the two CORAVEL[4] instruments, but additional systems discovered later in the course of our planet surveys met the same fate and were rejected

[4] The two CORAVEL instruments [2] were used extensively between 1977 and 1998 to monitor the radial velocity of more than 60 000 nearby stars at an intermediate precision (typically 300 m s^{-1}) in both hemispheres.

as well. Alternatively, single-lined spectroscopic binaries with long periods ($\gtrsim$10 years) were generally kept in the samples, since the presence of giant planets is more likely in these systems.

Our initial policy on close visual binaries was less drastic and most of these systems were kept in our ELODIE and CORALIE samples. However, the data accumulated in the early phases of the CORALIE program showed that radial-velocity measurements of the primary components of close visual binaries were generally noisier and more variable than expected, suggesting that the secondaries in these systems contribute to some extend to the recorded flux. Accordingly, visual binaries closer than $\sim$6$''$ and with a magnitude difference smaller than $\sim$4 were flagged as second-priority targets and observed less often than regular single stars.

2.2 Census of Planets in Binaries and Multiple Star Systems

Thanks mostly to recent searches for common proper motion companions to planet-host stars (Sect. 3), the number of planets known to reside in binaries and multiple stars has been growing rapidely in the past few years [6, 9, 14, 16, 38, 39, 42, 51] and now raises to 42 planets (or 35 planetary systems). A census of these planets is given in Table 1, which lists the planet-host systems with published planets and acknowledged evidence of a bound status for the stellar components.

Table 1 shows that most of the planets presently known to reside in binaries or multiple stars were found in systems with a separation larger than $\sim$100 AU. Although some theoretical models predict a shortage of giant planets in binaries closer than 100–120 AU, current Doppler surveys are too severely biased against these particular systems to allow for a definite conclusion. In particular, the fact that most of the few planets detected in binaries closer than 100 AU were found in systems with separations of about 20 AU likely reflects the selection effects just mentioned in Sect. 2.1. For instance, both γ Cephei and Gl 86 are long-period single-lined spectroscopic binaries with very fait secondaries ($\Delta V \sim 8.4$ and $\Delta V \gtrsim 8$, respectively). The presence of two such systems in our list confirms that searching for planets in long-period spectroscopic binaries with very faint secondaries is feasible using cross-correlation techniques. Similarly, HD 1237 and HD 177830 are visual binaries with very faint secondaries ($\Delta V \gtrsim 6$ and $\Delta V \gtrsim 6.7$) that have not revealed themselves directly in Doppler measurements so far. As to the planet found around HD 41004 A ($\Delta V = 3.7$), it is an object that is beyond the detection capabilities of classical Doppler surveys, but that is within the reach of surveys dedicated to the search for planets in close binaries (Sect. 4).

The lack of planets in binaries closer than $\sim$20 AU is potentially more interesting as it might be real. According to the most optimistic theoretical models, the closest binaries susceptible of hosting giant planets have a periastron distance of about 25 AU [4]. If this is correct, then most "short-period" spectroscopic binaries should be free from giant planets and the "limit" at

Table 1. Census of planets orbiting a component of a binary or multiple star system with confirmed orbital or common proper motion. CPM stands for common proper motion systems, VB for visual binaries showing hints of orbital motion, and SB for spectroscopic binaries. WD means that the stellar companion is a white dwarf.

Planet-host star	Proj. separation (AU)	Number of planets	Number of stars	Remark
HD 38529 A	~12000	2	2	CPM
HD 20782	~9113	1	2	CPM
HD 40979	~6400	1	2	CPM
HD 222582	~4740	1	2	CPM
HD 147513	~4441	1	2	CPM, WD
HD 213240 A	~3898	1	2	CPM
Gl 777 A	~3000	2	2	CPM
HD 89744 A	~2456	1	2	CPM
HD 80606	~1200	1	2	CPM
55 Cnc A	~1065	4	2	CPM
HD 11964 A	~1009	1	2	CPM
16 Cyg B	~850	1	3	CPM
HD 142022 A	~820	1	2	CPM
υ And A	~750	3	2	CPM
HD 178911 B	~640	1	3	CPM
HD 75289 A	~621	1	2	CPM
HD 196050 A	~501	1	3	CPM
HD 99492	~500	1	2	CPM
HD 109749 A	~493	1	2	CPM
HD 46375 A	~345	1	2	CPM
HD 114729 A	~282	1	2	CPM
HD 65216 A	~255	1	3	CPM
HD 27442 A	~240	1	2	CPM, WD
τ Boo A	~240	1	2	VB
HD 16141 A	~223	1	2	CPM
HD 189733 A	~216	1	2	CPM
HD 195019 A	~150	1	2	CPM
HD 114762 A	~130	1	2	CPM
HD 142 A	~105	1	2	CPM
HD 19994 A	~100	1	2	VB
HD 177830 A	~97	1	2	CPM
HD 1237 A	~68	1	2	CPM
HD 41004 A	~23	1	2	SB
γ Cephei A	~22	1	2	SB
Gl 86 A	~20	1	2	VB, SB, WD

~20 AU may have a true meaning. Nonetheless, the present observing material do not allow us to rule out the alternative hypothesis that the lack of planetary detections in systems closer than 20 AU actually reflects the discrimination against "short-period" spectroscopic binaries in classical Doppler surveys. On that basis, the question of the closest binaries susceptible of hosting circumstellar giant planets remains open. All we can say at present is that

giant planets were found in all types of binaries where we have looked for them.

Classical radial-velocity planet search programs have brought observational evidence that even spectroscopic binaries can host circumstellar giant planets, a fact that was not taken for granted previously. Nevertheless, the information provided by classical Doppler surveys is incomplete with regard to the closest binaries. Due to this incompletness, we can derive from the present census only a minimum value for the fraction of planets residing in double and multiple stars. This minimum fraction is 21%. Deriving the actual frequency of planets in binaries and probing the occurrence of planets in the closest systems both call for the need of planet search programs capable of dealing with spectroscopic and close visual binaries. Two such programs are presently underway [15, 32], and we discuss in Sect. 4 our own survey for planets in spectroscopic binaries.

2.3 Different Properties for Planets in Binaries?

The first hint that planets residing in binaries may possess some distinctive properties and characteristics was brought by [66], who pointed out that planets in binary systems seem to follow a different period-mass correlation than planets orbiting single stars. In a similar vein, we performed in 2003 a more comprehensive study based on a larger sample (19 instead of 9 planets in binaries), considering not only the period-mass but also the period-eccentricity diagram [16]. As shown in Fig. 1, our analysis confirms that the few planets with a minimum mass $M_2 \sin i \gtrsim 2$ $\mathrm{M_{Jup}}$ and a period $P \lesssim 40$ days all orbit the components of binaries or multiple stars. However, the inclusion in our sample of several newly discovered planets with periods longer than 100 days, masses in the range 3–5 $\mathrm{M_{Jup}}$, and found in binaries, decreases the significance of the negative period-mass correlation found by [66]. Yet, marginal signs of this correlation subsist in the form of a shortage of very massive planets ($M_2 \sin i \gtrsim 5$ $\mathrm{M_{Jup}}$) on long-period orbits ($P \gtrsim 100$ days).

Regarding the period-eccentricity diagram, our analysis emphasizes that the planets with periods $P \lesssim 40$ days and residing in binaries tend to have low eccentricities ($e \lesssim 0.05$) compared to their counterpart in orbit around single stars (Fig. 1). In other words, the minimum period for a significant eccentricity seems larger for planets in binaries ($P \sim 40$ days) than for planets around single stars ($P \sim 5$ days). The statistical significance of this finding is very modest, though, and calls for confirmation.

Assuming that the above trends are real, is it possible to understand and to explain these differences? A study by [30] shows that the migration and mass growth rates of a Jovian protoplanet are enhanced when the latter is embedded in a circumprimary disk in a binary system with a mean semimajor axis between 50 and 100 AU. At the same time, the eccentricity of such a protoplanet decreases with time due to the damping action of the disk. Taken at face value, these theoretical predictions may provide a nice and self-consistent

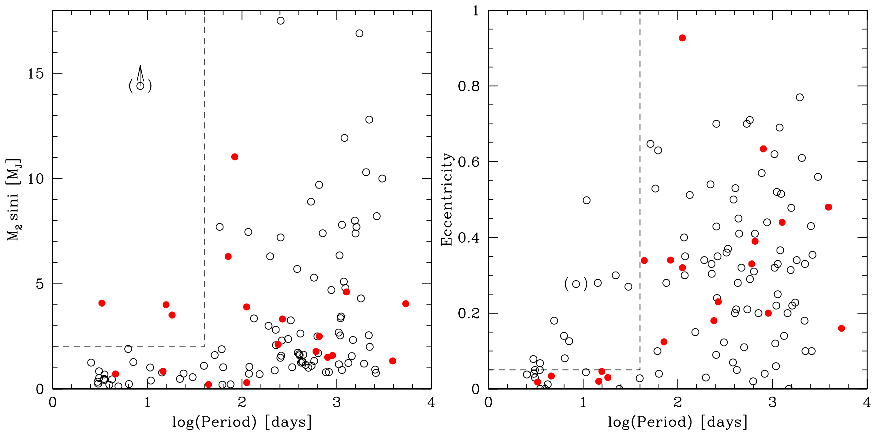

Fig. 1. Left: Minimum mass versus orbital period for all the extrasolar planetary candidates known in 2003. Planets orbiting a single star are represented as open circles, while planets residing in binaries or multiple star systems are represented as dots. The dashed line approximately delimits the zone where only extrasolar planets belonging to binaries are found. **Right:** Eccentricity versus orbital period for the same planetary candidates as before. The dashed line approximately delimits the region where no planet-in-binary is found.

explanation for the observation that the most massive short-period planets are all found in binaries and have small eccentricities. However, the weak point in this reasoning is that the five planets with a period shorter than 40 days and found in binaries reside in systems with very different separations, from $\sim$20 to $\sim$1000 AU. Although these separations are not true semimajor axes (orbital parameters are unknown for most of theses binaries) and although it would probably be more appropriate to consider periastron distances rather than semimajor axes, it seems very likely that several of these five systems are quite different from the binaries modeled by [30].

An alternative explanation that would be valid for wide binaries is the so-called Kozai migration, a migration process specific to binaries and resulting from the coupling of the Kozai mechanism with tidal dissipation [64]. Nonetheless, even if the Kozai mechanism can account for the high eccentricity of given planetary candidates such as 16 Cyg Bb and HD 80606 b [25, 37, 64], it has never been demonstrated that Kozai migration may account for the existence of close-in planets with very low eccentricities. In addition, several requirements must be simultaneously satisfied for the Kozai mechanism to operate, meaning that Kozai migration alone is unlikely to explain the distinctive characteristics of the five shortest period planets found in binaries.

To summarize, the emerging trends seen in the period-mass and period-eccentricity diagrams may be consistent with the idea that migration has played an important role in the history of short-period planets residing in binaries, and these results may be an indication that planetary migration

proceeds differently in binaries than around single stars. However, owing to the very different types of systems they reside in, the properties of the five planets with a period shorter than about 40 days seem difficult to explain by invoking a single migration mechanism such as disk-planet interactions or Kozai migration.

As just shown, the first analyses devoted to the examination of possible differences in the characteristics and orbital properties of planets found in binaries and around single stars have come up with positive results. Yet, these analyses are far from being on robust statistical grounds and there is room for improvement (see [9, 39] for more recent analyses). One limiting factor in these studies is the small size of the planets-in-binaries sample that renders the results highly sensitive to the inclusion of additional new candidates. This observation, coupled to the fact that short-period planets found in binaries may be more massive on average, constitutes an additional strong argument to promote the search for short-period planets in close binaries. Another weak point in these analyses is that they implicitly assumed that planet-host stars without known stellar companions were single stars, though the presence of stellar companions had never been systematically probed. Conducting systematic searches for stellar companions to the known planet-host stars constitute therefore another prerequisite step in more comprehensive studies aimed at investigating how companion stars affect planetary properties. This issue will be the subject of the next section.

3 Results from Imaging Surveys

As outlined in the introduction, the problem of quantifying the impact of stellar duplicity on planet occurrence can be tackled in a somewhat indirect way by comparing the multiplicity of planet-bearing stars to the multiplicity of similar stars but without known planetary companions. This approach was first followed by [42], who probed the multiplicity status of 11 planet-host stars and concluded that the companion star fraction for planet-bearing stars is not significantly different from that of field stars. Nonetheless, given the different outcomes and conclusions of theoretical studies on the formation of giant planets in binaries closer than $\sim$100 AU, and given that more than 170 planet-host stars are known today, the multiplicity of planet-bearing stars clearly merits reconsideration.

To probe the multiplicity status of actual and potential planet-host stars, we initiated in 2002 a large-scale adaptive optics search for close stellar companions to nearby stars with and without known planetary companions [14, 17, 18, 58]. The main goal of this program is to obtain a first quantification of the major effects of stellar duplicity on planet formation and evolution, with an emphasis as to whether or not the occurrence of giant planets is reduced in the presence of a close stellar companion. In order to access a large part of the celestial sphere, the main program was divided into two sub-

programs: a northern and a southern survey. The southern survey has been carried out with the NAOS-CONICA (NACO) facility (Very Large Telecope (VLT), Paranal Observatory, Chile), while the northern survey has been conducted with the PUEO-KIR adaptive optics system (Canada-France-Hawaii Telescope, Hawaii). In this section we present and discuss the results from our southern survey, which is the closest to completion.

3.1 The Multiplicity Status of Nearby Stars With and Without Planets Probed with VLT/NACO

The NACO survey

In an effort to be as rigorous as possible, we included in our NACO survey both planet-host stars and comparison stars showing the least evidence for planetary companions from radial-velocity measurements. The inclusion of a comparison subsample was motivated by two main reasons. First, radial-velocity planet search programs suffer from noticeable selection effects against the closest binaries and these biases must be taken into account to obtain meaningful results. Second, statistical studies must compare the multiplicity among planet-host stars with the multiplicity among similar stars but without planetary companions. In addition, we needed a reference point spread function (PSF) star to characterize the adaptive optics system performance and to identify PSF artifacts on each of our images. To fulfill all these requirements at once, we selected a subsample of comparison stars within our CORALIE planet search sample and included these stars in our adaptive optics survey. Proceeding in this way, we have at hand high-precision radial-velocity data that place constraints on the potential planet-bearing status of each comparison star, we match the target selection criteria for radial-velocity planet searches, and we minimize the corrections related to observational effects.

Our NACO survey therefore relies on a sample of 57 planet-host stars, together with 73 comparison stars carefully chosen so that they can be used both as comparison stars for the scientific analysis and as PSF reference stars in the data reduction process. Note that we purposely rejected from our observing list the 11 planet-host stars already observed by [42]. However, these stars will be included in our statistical analysis (Sect. 3.2), balancing the two subsample sizes to about 70 stars in each subsample.

The observing strategy of the survey consisted of taking a first image of each of our targets (planet-host and comparison stars) in order to detect companion candidates. To discriminate between true companions and unrelated background or forground stars, we relied on two-epoch astrometry. For relatively wide and bright objects ($\rho \gtrsim 10''$, $K \lesssim 14$), a preexisting astrometric epoch could usually be found in the data from the Two Micron All Sky Survey (2MASS, [54]), meaning that only one NACO observation was needed. Nevertheless, due to the high angular resolution and the small field of view of NACO, we could not rely on such preexisting data in a general way. As far

as possible, our targets with companion candidates were thus observed twice during the survey to check for common proper motion.

Detections and Observational Results

Altogether, we found 95 companion candidates in the vicinity of 33 of our targets. Among the 61 companion candidates with multiepoch observations, 19 are true companions and 1 is likely bound. The companionship status of the 34 companion candidates with only one observing epoch remains formely unknown, but calculations of individual likelihood of chance alignment show that most of these objects are likely background stars (see [14] for further details).

Among planet-host stars, we discovered two new companions to HD 65216, one to HD 177830, and we resolved the previously known companion to HD 196050 into a close pair of M dwarfs. Our data additionally confirm the bound nature of the companions to the planet-host stars HD 142, HD 16141 and HD 46375 (Table 1), along with the unbound status of a close and relatively bright companion to HD 162020. The two companions to HD 65216 form a tight binary (projected separation of 5 AU) and are probably very low mass stars at the bottom of the main sequence. HD 65216 therefore joins the small group of triple star systems hosting a planet. The same is true for HD 196050, which was previously thought to be a binary [39], but turned out to be a triple when observed at the NACO resolution. Like the triple system HD 178911, HD 65216 and HD 196050 are made of a single planet-host star in orbit with a more distant binary, but contrary to HD 178911 they contain stars with very different masses (G primaries, M/L secondaries and tertiaries). As the discovery a such systems requires high angular resolution and high-contrast data, it is not very surprising that we found two in our NACO survey whereas none was previously known (or recognized as such). The newly found companion to HD 177830 is an early M dwarf located at a projected separation of 97 AU. Note that HD 177830 is not a main-sequence star but an evolved K0 subgiant.

Survey Sensitivity and Parameter Space Surveyed

For G0 primaries, the typical sensitivity of our survey enabled us to detect companions down to M4–M5 dwarfs at $0.2''$ and all M dwarf companions above $0.65''$. For K0 primaries, we detected companions down to M5–M6 dwarfs at $0.2''$ and we reached the substellar domain above $0.65''$. Our survey thus provides us with a very complete census of the stellar multiplicity among planet-host stars for mean semimajor axes in the range 35–230 AU, allowing us to probe a large fraction of the most interesting and sensitive separation range according to planet-formation models (i.e. the region below and around 100–120 AU).

3.2 The Global Impact of Stellar Duplicity on Planet Occurrence

The observational results obtained in the context of our NACO survey form an unprecedented data set to study the impact of stellar duplicity on planet formation and evolution. Indeed, adding to our own results the targets surveyed by [42] we now have a precise and homogeneous census of the multiplicity status of 68 planet-host stars. As importantly, we now also have a comparison subsample of 73 stars with both high-precision radial-velocity measurements and adaptive optics data, so that we can effectively compare some of the statistical properties of planet-bearing stars with those of similar stars showing no evidence for planetary companions. This statistical analysis is currently in progress. We present here a preliminary and simplified version aimed at obtaining a first quantification of the global impact of stellar duplicity on planet occurrence in binaries with mean semimajor axes between 35 and 230 AU.

As already mentioned, Doppler planet searches are biased in some ways against the closest binaries and these selection effects must be taken into account to obtain meaningful results. The two main selection effects associated with Doppler planet search programs are visible in Fig. 2, which shows the detections and sensitivity limits from our NACO survey. This figure emphasizes a shortage of systems with angular separations below $\sim$0.8$''$. This paucity of very close companions is neither real nor due to a bad estimation of our detection limits, but simply reflects the systematic rejection of most spectroscopic binaries from the CORALIE sample. Another striking feature in Fig. 2 is the small number of companions with a magnitude difference smaller than 3 in the H band and smaller than 2–3 in the K band. This is a signature of the rejection of close visual binaries with bright secondaries, i.e. the systems with an angular separation below $\sim$6$''$ and a magnitude difference in the V band smaller than $\sim$4, which translates into a magnitude difference of about 2.2 in the K band. Since we were very careful with the selection of our comparison subsample, our two NACO subsamples are biased in the same way with respect to these selection effects and the results obtained for planet-host and for comparison stars can be compared directly, at least for a preliminary analysis.

In order to quantify the global impact of stellar duplicity on planet occurrence we use the binary fraction. As explained in the introduction, if stellar duplicity hampers planet formation or threatens the long-term survival of planets, the binary fraction of planet-host stars should be smaller than the binary fraction of comparison stars. Alternatively, if the presence of a close stellar companion favors planet formation one way or another, the binary fraction of planet-host stars should be greater than that of comparison stars.

As a first step in the analysis we computed the binary fraction for both subsamples, considering true and likely bound companions with angular separations in the range 0.8–6.5$''$ and located within the most restrictive detection limits of either of the two bands (H and K) used in our survey. On that basis, the binary fraction for planet-host stars is $8.8 \pm 3.5\%$, while the binary fraction for comparison stars is $12.3 \pm 3.2\%$. The two binary fractions are thus

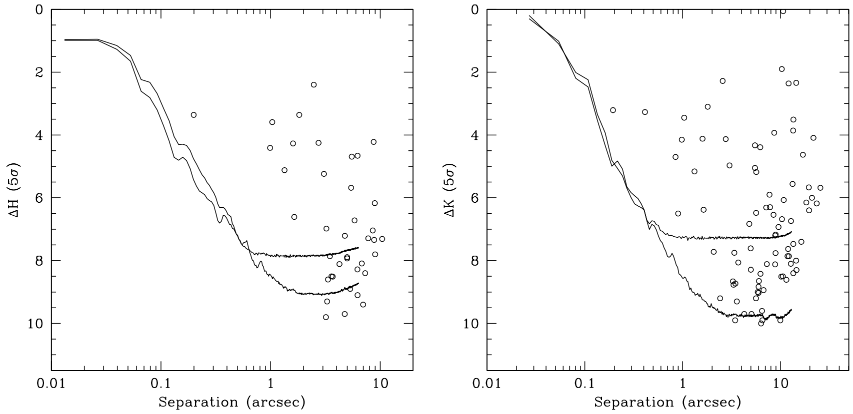

Fig. 2. Summary of the detections (open circles) and median sensitivity limits (solid lines) from our NACO survey in the H (left) and K (right) bands. The original detector of CONICA was replaced in the middle of our program, hence two sensitivity limits for each band.

basically compatible within error bars, though the binary fraction for planet-host stars might be slightly smaller. In any case, these results show that the presence of a stellar companion with a mean semimajor axis between 35 and 230 AU does not favor planet occurrence to a significant extent.

To investigate in more detail the potentially negative impact of stellar duplicity on planet occurrence in the closest systems, we divided our two subsamples in two, following theoretical predictions that place a limit at 100–120 AU between the regime of close binaries in which planet formation might be affected by stellar duplicity, and wider binaries in which planet formation proceeds like around single stars. Recomputing the binary fractions for our two subsamples, but considering only the systems closer than 120 AU, yields a binary fraction of $2.9 \pm 2.1\%$ for planet-host stars and of $9.6 \pm 3.5\%$ for comparison stars. Similarly, the two binary fractions for the wider systems are $5.9 \pm 2.0\%$ for planet-host stars and $2.7 \pm 2.9\%$ for comparison stars. According to these results, the binary fractions for planet-host and comparison stars are compatible for binaries with a mean semimajor axis between 120 and 230 AU, while they differ at the 1.6σ level for closer binaries. The main result of our analysis is thus that the occurrence of planets is reduced in binaries closer than ∼120 AU. Even though the statistical significance of this result is quite modest, this is an important finding.

Given the range of semimajor axes considered in our analysis, the lower frequency of planets in binaries closer than ∼120 AU is likely to be related to the formation of the planets rather than their long-term survival. Recalling the conclusions from theoretical studies, one possible explanation to our findings would be that disk instability is indeed a viable mechanism for the formation

of giant planets and that this mechanism gets inhibited in binaries closer than ∼120 AU, as suggested by [36]. However, one weak point in this reasoning is that [36] did not actually study planet formation via core accretion. Their prediction that the formation of giant planets via core accretion proceeds undisturbed in binaries with separations down to ∼60 AU is based solely on the temperature profiles of their simulated disks, while additional effects may come into play to inhibit planet formation. Consequently, our results might alternatively indicate that core accretion is the main formation mechanism for giant planets, but that its efficiency is reduced in binaries closer than ∼120 AU. This point of view may be consistent with the conclusion by [57] that planetesimal accretion is possible in the γ Cephei system (semimajor axis of 18.5 AU), but requires a delicate balancing between gas drag and secular perturbations by the secondary star.

To sum up, the present results from our NACO survey constitute the first observational evidence that the frequency of planets is reduced in binaries closer than ∼120 AU. Nonetheless, further investigations on both the theoretical and the observational sides will be needed to put this result on robust statistical grounds and to fully explain the origin of this lower frequency. Regarding observations, we are working on a more comprehensive and refined version of the preliminary analysis just presented, also taking into account the recent results from the survey by [6]. The next step in the analysis will be to include the results from our PUEO northern survey. On the one hand this will provide us with an improved statistics to study the global impact of stellar duplicity on planet occurrence, while on the other hand this new material will enable us to reconsider the emerging trends outlined in Sect. 2.3 regarding possible differences in the properties of short-period planets residing in binaries. Last but not least, we would like to better characterize the implicit assumption made throughout our discussion that most planet-host stellar systems closer than ∼120 AU have retained their current orbital configuration ever since the planets formed. As explained in the introduction, a direct quantification of the occurrence of giant planets in the closest binaries might provide some observational constraints on this point.

4 Results from Radial-Velocity Planet Searches in Spectroscopic Binaries

Planet searches in close binaries (i.e. systems closer than 2–6″) used to be of marginal interest until 2000–2002. The discovery of Gl 86 b, the first planet found in a spectroscopic binary [50], and the observation that the most massive short-period planets all orbit the components of double or multiple star systems [60, 66] changed this point of view and led to an ever-increased interest for planet searches in close binaries. Yet, classical Doppler surveys do not avoid most close binaries without reason. The main issue with close binaries is that each stellar component cannot be observed individually. That

is, Doppler data of close binaries consist not of single stellar spectra but of composite spectra made of two (or possibly more) stellar spectra. Obviously, this introduces some complications into the extraction of the radial velocities, rendering classical cross-correlation techniques not well adapted to the search for circumstellar planets in close binaries. The inclusion of close binaries into radial-velocity planet searches thus necessitated the development of data reduction techniques specially designed to extract precise radial velocities from composite spectra.

A rather natural way to analyze composite spectra and to extract precise radial velocities for the individual components of close binaries is to generalize the concept of cross-correlation to that of two-dimensional correlation. This approach was followed some time ago by S. Zucker and T. Mazeh, who developed a two-dimensional correlation algorithm named TODCOR [65]. Following our intention to include spectroscopic binaries in our radial-velocity planet searches, we teamed up with S. Zucker and T. Mazeh, who modified their TODCOR algorithm to allow it to work with our ELODIE and CORALIE echelle spectra. This resulted in a new multi-order TODCOR algorithm [67], which has already produced some very interesting results [18, 19, 67, 68] and which we are now using extensively to search for planets in spectroscopic and close visual binaries.

We present and discuss in this section some results from our ongoing searches for planets in spectroscopic binaries. Our presentation will follow an increasing order of difficulty in terms of radial-velocity extraction, starting with the easiest systems that are single-lined spectroscopic binaries (SB1s) and ending with the more complicated double-lined spectroscopic binaries (SB2s).

4.1 Searching for Planets in SB1s: Our Survey for Short-Period Circumprimary Planets

In order to obtain a first quantification of the occurrence of planets in the closest binaries susceptible of hosting circumstellar planets we initiated in 2001 a systematic radial-velocity search for short-period circumprimary planets in SB1s [15, 18]. The restriction of our survey to SB1s was motivated by two considerations. First, the faintness of the secondary components in these systems gave us good hopes that we could use our standard cross-correlation technique to extract precise radial velocities for the primary components. Second, the prospects of planet formation and survival might be brighter in SB1s than in SB2s, which have similar separations but more massive secondaries. Our survey for giant planets in SB1s was thus designed as a first exploratory investigation that may be complemented later, in the case of positive results, by an additional survey targeting SB2s .

Sample and Observations

Our sample of binaries was selected on the basis of former CORAVEL surveys carried out to study the multiplicity among G and K dwarfs of the solar neighborhood [11, 24]. Basically, we retained all the 140 SB1 candidates with a period longer than ∼1.5 years, some of them with well-characterzied orbits, others with long-period drifts. Note that CORAVEL velocities have a typical precision of 300 $\mathrm{m\,s^{-1}}$ and thus cannot be used to search for planets. To search for planets in our 140 SB1s we took 10 to 15 additional high-precision radial-velocity measurements of each system, either with the ELODIE spectrograph (Observatoire de Haute-Provence, France; [3,45]) or with the CORALIE spectrograph (La Silla Observatory, Chile; [43, 50, 61]). Given our initial aim to analyze these high-precision data with standard cross-correlation techniques, we rejected during the observations the systems that turned out to be SB2s at the higher resolution of ELODIE and CORALIE, as well as the binaries that were resolved within the guiding field of the telescope. After this additional selection we ended up with 101 SB1s that form the core of our survey.

First Analysis Based on Cross-Correlation

As a first step in the analysis, the spectra obtained with ELODIE and CORALIE were reduced online and the radial velocities extracted using our standard cross-correlation pipeline. When searching for planets in binaries, what we are interested in are not the radial velocities themselves but the residual (radial) velocities around the binary orbits. The planet search was thus carried out by searching for short-period variations in these residual velocities.

Figure 3 shows the distribution of the residual-velocity variations for our 101 targets. These variations are quantified by a normalized root-mean-square (rms), which is the ratio of the external error (i.e. the standard deviation around the orbit or around the drift) to the mean internal error (i.e. the mean of individual photon-noise errors). According to Fig. 3, most of our targets (74%) have a normalized rms close to 1, indicating that no source of radial-velocity variation other than the orbital motion is present (see Fig. 4 for an example). In contrast, 12.5% of our targets are clearly variable and exhibit a normalized rms greater than 3 (see Fig. 4 for an example). The remaining systems (13.5%) are marginally variable with a normalized rms between 2 and 3.

In terms of planetary prospects the most interesting systems are the variable and marginally variable binaries. Nevertheless, the presence of a planetary companion in orbit around the primary star is not the only way to produce residual-velocity variations like those observed. Alternative possibilities include: (i) the primary star is intrinsically variable, (ii) the system is an unrecognized SB2, and (iii) the system is in fact triple and the secondary is itself a short-period spectroscopic binary. Assuming that planets are as

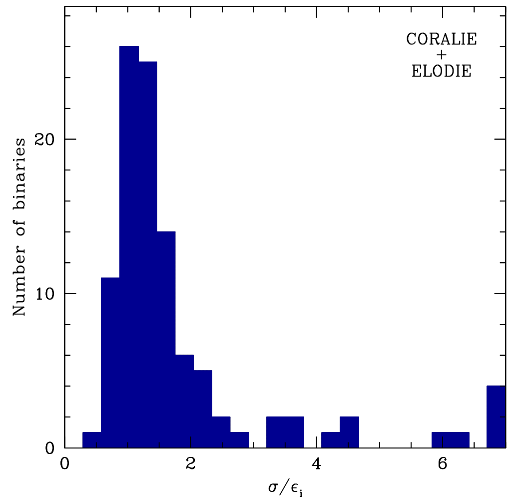

Fig. 3. Normalized residual-velocity rms for all our SB1s. σ is the standard deviation around a Keplerian orbit or around a drift, while ϵ is the mean measurement uncertainty. Systems with a rms larger than 7 are all gathered together in the last bin.

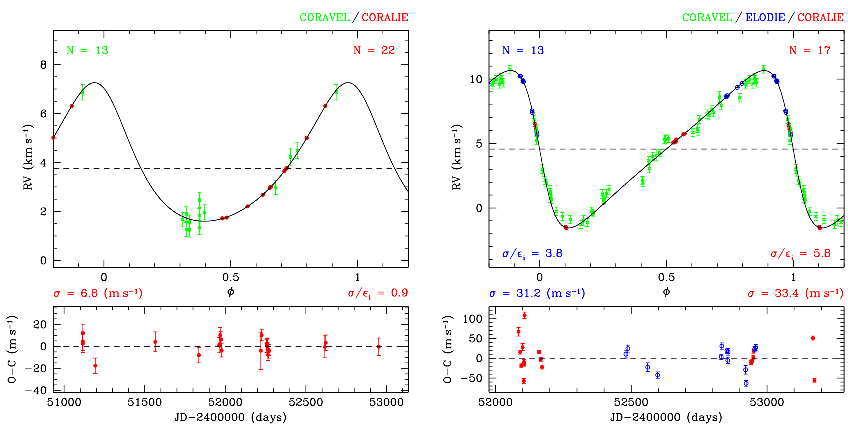

Fig. 4. Left: Example of a binary exhibiting no residual-velocity variation. CORAVEL data are depicted as stars (large error bars), while CORALIE data are depicted as dots. The bottom panel shows the residual velocities (CORALIE data only). **Right:** Example of a binary with variable residual velocities. This system was exceptionally observed with both ELODIE and CORALIE. Figures on the left refer to the ELODIE velocities (represented as circles), while figures on the right refer to the CORALIE velocities (represented as dots).

common in close binaries as around single stars, we expect to find only one or two planets more massive than 0.5 M_{Jup} and with a period shorter than ∼40 days in our sample. This rough estimation shows that most of the observed residual-velocity variations are probably not related to the presence of planetary companions, but likely stem from the binary or multiple nature of our targets. Therefore, to identify the few potential planet-bearing stars among the many variable and marginally variable systems we must find a way to precisely characterize the cause of the residual-velocity variations.

Identifying the Origin of Residual-Velocity Variations

Binaries with instrinsically variable primaries can be identified like single active stars by considering the chromospheric emission flux in the Ca II H and K lines. Using cross-correlation techniques, identifying triple systems and unrecognized SB2s is feasible is some instances (see e.g. [15, 18, 53]), but two-dimensional correlation is a much more efficient tool to this purpose. Accordingly, we are presently analyzing all the variable and marginally variable systems with the two-dimentional algorithm TODCOR, trying to identify unrecognized SB2s and triple systems. This work is just beginning and only four variable systems have been studied in some detail thus far. Of these four systems, two turned out to be triple star systems (see Fig. 5 or [15, 18] for an example), while the two others turned out to be regular binaries with small relative velocities (see Fig. 6 for an example). Not any of these four systems shows hints of the presence of a circumprimary planet.

Preliminary General Results

The present results from our search for circumprimary short-period planets in SB1s show that in most of these systems (74%) the secondary component is so faint ($\Delta V \gtrsim 6$) that it does not contribute significantly to the recorded flux. Doppler data of such systems can be analyzed like Doppler data of single stars and the precision achieved on the measurement of the radial velocity of the primary star is as good as for single stars. These SB1s can thus be included in classical radial-velocity planet searches.

In contrast, analyzing the Doppler data of the 26 SB1s that exhibit residual-velocity variations is not as straightforward. In many of these systems the secondary component (and possibly the tertiary component as well) significantly contributes to the recorded flux ($\Delta V \in [\sim 3, \sim 6]$), rendering the use of two-dimensional correlation mandatory to unambiguously identify the origin of the variations observed and hence to search for circumprimary planets. Our current results do not enable us to precisely characterize our detection capabilities in terms of circumprimary planet searches, but we estimate that typical precisions on the radial velocity of the primary star range between 10 and 20 $\mathrm{m\,s^{-1}}$. Although these precisions are not as good as for single stars, they remain good enough to search for giant planets.

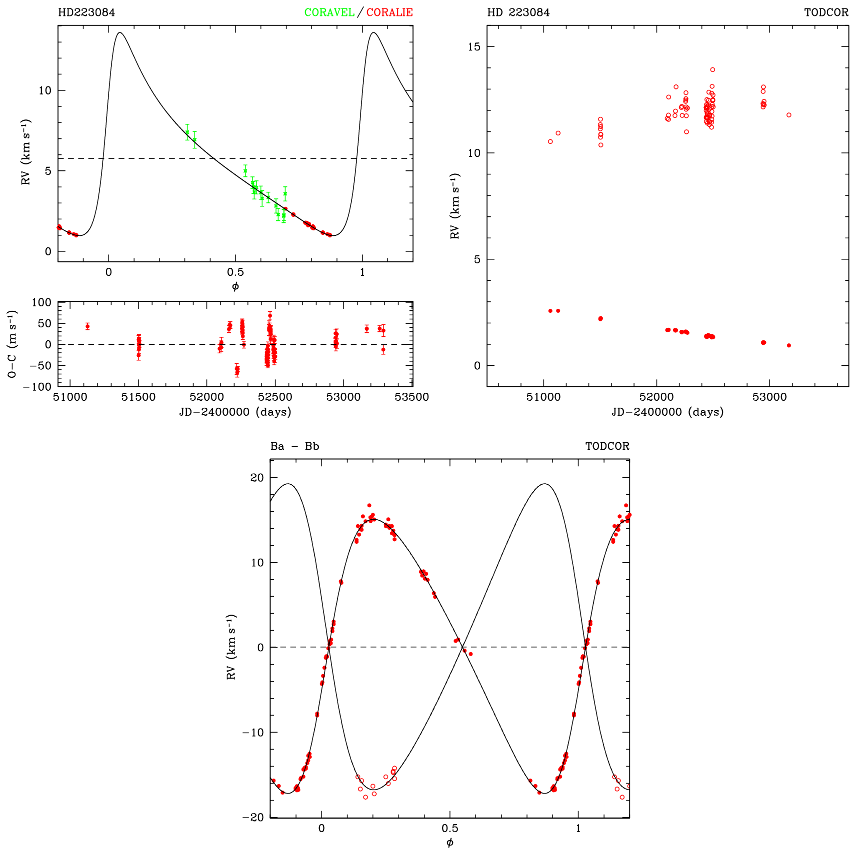

Fig. 5. An example of triple system: HD 223084. **Top left:** CORAVEL (crosses, large error bars) and CORALIE (dots) velocities for HD 223084. The binary orbit is tentative and is used only as a proxy to compute residual velocities. The bottom panel shows the residual velocities (CORALIE data only). **Top right:** TODCOR velocities for HD 223084 A (dots) and HD 223084 Ba (open circles) after having removed the 202-day modulation of the Ba–Bb inner pair. **Bottom:** SB2 orbit for HD 223084 Ba (dots) and HD 223084 Bb (open circles). This orbit is characterized by a period of 202 days and velocity semiamplitudes of 16.1 $\mathrm{km\,s^{-1}}$ and 18 $\mathrm{km\,s^{-1}}$ for components Ba and Bb, respectively.

The preliminary results from our search for circumprimary giant planets in SB1s thus confirm that such a program has grounds for existence. So far, our survey has unveiled no promising planetary candidate, but the data of 22 variable and marginally variable systems remain to be analyzed in detail with two-dimensional correlation. Since contamination effects stemming from the stellar companions are likely to prevail over potential planetary signals, two-dimensional analyses must be completed before concluding on the existence,

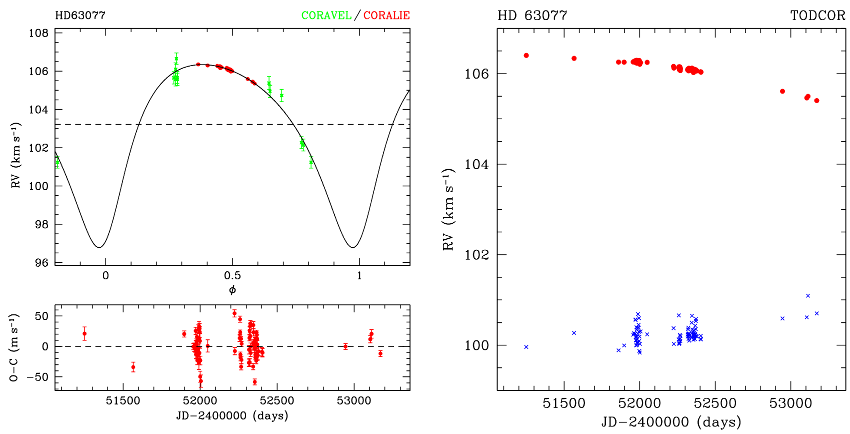

Fig. 6. An example of unrecognized SB2: HD 63077. **Left:** CORAVEL (crosses, large error bars) and CORALIE (dots) velocities for HD 63077. The binary orbit is tentative and is used only as a proxy to compute residual velocities. The bottom panel shows the residual velocities (CORALIE data only). **Right:** TODCOR velocities for HD 63077 A (dots) and HD 63077 B (crosses). The opposite slopes of the two components are clearly seen.

or absence, of planets in our sample. All we can say at present is that less than 22% of the SB1s from our sample have a short-period ($P \lesssim 40$ days) giant ($M \gtrsim 0.5$ $\mathrm{M_{Jup}}$) planetary companion. Definitive results from our survey will enable us to obtain a much tighter constraint.

4.2 Searching for Planets in SB2s: the Example of HD 188753

Double-lined spectroscopic binaries have not been systematically included in our observing programs yet, so that our experience with planet searches in these binaries is limited to a few systems. Among those is HD 188753, a close triple star system hosting a short-period giant planet (a hot Jupiter) according to [31]. In this section we present our data and analysis of HD 188753, which do not confirm the existence of this hot Jupiter [19]. Beyond the debate, HD 188753 constitutes a concrete example of some of the challenges faced by Doppler searches for planets in spectroscopic binaries.

HD 188753 has attracted much attention since July 2005 when [31] reported the discovery of a 1.14-$\mathrm{M_{Jup}}$ planet on a 3.35-day orbit around the primary component of this triple star system. Aside from the planet, HD 188753 consists of a primary star (HD 188753 A) orbited by a visual companion, HD 188753 B, which is itself a spectroscopic binary (i.e. HD 188753 B is actually made of two stellar components, HD 188753 Ba and HD 188753 Bb). The visual orbit of the AB pair is characterized by a period of 25.7 years, a semi-major axis of 12.3 AU (0.27″ separation) and an eccentricity of 0.5 [55], while the spectroscopic orbit of HD 188753 B has a period of 155 days [22,31]. What

renders this discovery particularly important and interesting is that the periastron distance of the AB pair may be small enough to preclude giant planet formation around HD 188753 A according to the canonical planet-formation models [4, 28, 36, 41]. The discovery of a close-in giant planet around this star has thus been perceived as a serious challenge to planet-formation theories, though the alternative possibility that HD 188753 A might have acquired its planet through dynamical interactions was also pointed out [46, 49].

Following the announcement by [31], we monitored HD 188753 during one year with the ELODIE spectrograph, gathering a total of 48 spectra. The cross-correlation at the telescope immediately revealed the double-lined nature of HD 188753, the cross-correlation function consisting of two blended features corresponding to components A and Ba, respectively. The contribution of the third component (Bb) to the total flux is quite modest, so that the system can basically be considered as a double-lined spectroscopic binary.

Given the double-lined nature of HD 188753 and the strong line blending, we derived the radial velocities of HD 188753 A and HD 188753 Ba using the TODCOR algorithm. These velocities are displayed in Fig. 7. Our results for HD 188753 Ba confirm that it is indeed a spectroscopic binary with a period of 155 days. As to HD 188753 A, the dominant motion seen in our data is a steady decrease in velocity, fully consistent with the 25.7-year orbital motion of the AB pair. However, our radial velocities show no sign of the additional 3.35-day planetary signal reported by [31]. Instead, the residuals around the long-period drift are basically noise (Fig. 7) and the rms of 60 $\mathrm{m\,s^{-1}}$ can be interpreted as the precision we achieve on the measurement of the radial velocity of this star. Monte Carlo simulations run to check our ability to detect the potential planet around HD 188753 A show that we had both the precision and the temporal sampling required to detect a planetary signal like the one reported by [31]. On that basis, we conclude that our data show no evidence of a 1.14 $\mathrm{M_{Jup}}$ on a 3.35-day orbit around HD 188753 A.

While three planets have been discovered so far in binaries with a separation of $\sim$20 AU (Table 1), the planet found around HD 188753 A was the only planet known to reside in a tighter system. Therefore, the removal of HD 188753 Ab from the list of planetary candidates not only eliminates a potential source of difficulty for theorists, but also brings further support to the idea that the "limit" at 20 AU might be associated with a minimum separation for considering that a binary possibly harbors a giant planet.

Our experience with SB2 systems is as yet too limited to enable us to characterize our detection capabilities in terms of planet searches around the primary stars in these binaries. Nonetheless, in view of the results presented in Sect. 4.1, the precision of 60 $\mathrm{m\,s^{-1}}$ obtained on the radial velocity of HD 188753 A looks abnormally poor. Further investigations are underway to specify the main factor that limits our current precision on the radial velocity of HD 188753 A. In any way, the triple nature of HD 188753 allows us to hope that better precisions may be achieved for the primary components of true SB2s.

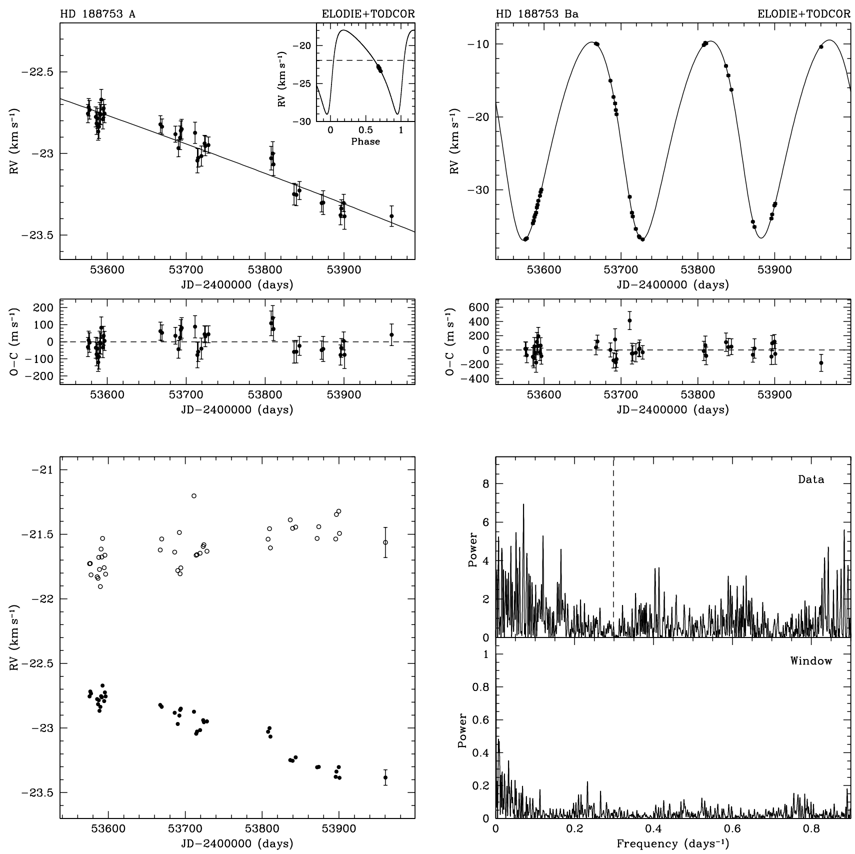

Fig. 7. Top: Radial velocities and orbital solutions for HD 188753 A (left) and HD 188753 Ba (right). For component A, the solid line represents the 25.7-year orbital motion of the visual pair shown in full in the inset. For component Ba the orbital solution corresponds to the 155-day modulation and it includes a linear drift to take the 25.7-year orbital motion into account. **Bottom left:** Radial velocities for HD 188753 A (dots) and for HD 188753 Ba after having removed the 155-day modulation (open circles). For the sake of clarity, only a typical error bar is displayed on the last measurement of each component. **Bottom right:** Lomb-Scargle periodogram of the residuals around the 25.7-year orbital motion for HD 188753 A. The 1% false alarm probability corresponds to a power of 9.4 and is represented by the top of the box. The dashed line denotes the frequency of the planetary signal reported by [31].

5 Conclusion and Perspectives

Over the past five years, binaries have become increasingly interesting targets in terms of planet searches. One the one hand, Doppler surveys have shown that giant planets exist not only in wide binaries but also in the much closer

spectroscopic binaries, raising the possibility that planets might be common in binaries and multiple stars. On the other hand, theoretical studies have shown that the presence of a close ($\lesssim$100-120 AU) stellar companion affects the formation and subsequent evolution of circumstellar giant planets, leaving some imprints in the occurrence, characteristics, and properties of the planets residing in these systems. The study of circumstellar planets in close binaries might thus provide a unique means to probe the main formation mechanism for giant planets and to bring observational constraints for planet-formation models.

Imaging surveys searching for stellar companions to planet-bearing stars have been very successful, yielding a precise characterization of the multiplicity status of more than half of the known planet-host stars. More importantly, our NACO survey has provided us not only with the multiplicity status of $\sim$70 planet-host stars, but also with the multiplicity status of the same number of comparison stars showing the least possible evidence for planetary companions and affected by the same selection effects than planet-host stars. A preliminary statistical analysis of this unprecedented data set brings the first observational evidence that the occurrence of planets is reduced in binaries closer than $\sim$120 AU. Given our present knowledge of planet-formation mechanisms, at least two different explanations can be put forward to explain this result: either disk instability is a viable formation mechanism that accounts for the existence of a significant number of the planets known presently, or core accretion is the main formation channel but its efficiency is reduced in binaries closer than $\sim$120 AU. Differentiating between these two possibilities will require some additional work, both on the theoretical and on the observational sides. Yet, the important point to notice is that observations have caught up with theoretical studies on the investigation of the impact of stellar duplicity on giant planet formation, meaning that some theoretical predictions can now be confronted with observational results.

The recent discoveries from imaging surveys have somewhat decreased the statistical significance of the emerging trends suggesting that short-period planets found in binaries and multiple stars possess distinctive characteristics and properties compared to their counterparts orbiting single stars. The most robust feature in this respect is still the observation that the few most massive short-period planets all orbit the components of binaries or triple stars. Nonetheless, such planets are still sparse (no new discovery since 2003) and even the most recent statistical studies remain affected by the uncertain multiplicity status of a large number of planet-host stars. The combined results from our NACO and PUEO surveys will remove this last uncertainty to a large extent, allowing for a major reinvestigation of possible differences in the eccentricity distributions of planet-host stars found in binaries and around single stars.

During the last few years, significant effort has been put into extending radial-velocity planet searches to spectroscopic and close visual binaries. Doppler surveys dedicated to these close systems have proven that the main

difficulties associated with the recording of composite spectra can be overcome by the use of two-dimensional correlation algorithms. In a general way, planet searches in close binaries are still in their early phases and only partial results are available yet. Nonetheless, current results demonstrate that Doppler searches for giant planets in single-lined and in some types of double-lined spectroscopic binaries are technically feasible. Searches for lower mass planets in some types of close binaries are not excluded a priori, but developing the technique further will first require a better understanding of the main limiting factors.

Final results from the presently ongoing planet searches in spectroscopic binaries are awaited with great interest for several reasons. First, these surveys constitute the only current possibility to probe the occurrence of giant planets in the closest binaries and to characterize the closest systems susceptible of hosting circumstellar giant planets. In this context, Doppler searches for planets in spectroscopic binaries will provide us with stronger constraints on the reality of the 20-AU "limit" and on its possible interpretation as a minimum separation for considering that a binary possibly harbors a giant planet. Second, the outcomes from planet searches in spectroscopic binaries will allow us to quantify the occurrence of giant planets in binaries closer than $\sim$35 AU. This, in turn, will nicely complement the results from our NACO and PUEO surveys. Gathering together the observational results from our imaging and radial-velocity programs might then provide us with some constraints as to whether most giant planets found in binaries closer than $\sim$50 AU actually formed in these systems, or were deposited at their present location through dynamical interactions. Finally, radial-velocity planets searches are the best tool to expand the size of the still limited sample of planets residing in binaries and multiple stars.

As planet searches progress, the conviction that planets are common objects in the universe continually strengthen. The discovery of giant planets in environments previously considered as relatively hostile to their existence (spectroscopic binaries, pulsars, ...) has contributed to this development, showing that planet formation is not as easily inhibited as originally thought. In addition to the encouraging results obtained thus far, the expectation that terrestrial planets form alongside their Jovian counterparts suggests that discoveries are limited by instrumental sensitivity rather than the availability of planets. Even if the presence of a close stellar companion lowers the efficiency of planet formation, theoretical studies support the existence of circumstellar terrestrial planets in many types of binaries. On the other hand, circumbinary planets are also expected to exist and searches for circumbinary planets offer a still unexplored field of investigation for planet hunters. Planet searches in and around binaries are thus not only meaningful, but also desirable in view of the potential information they can yield on the overall frequency of planets and on the processes underlying planet formation and evolution.

Acknowledgement. We thank A.-M. Lagrange for helpful comments on our manuscript.

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